EARTH SURFACE PROCESSES AND LANDFORMS, VOL. 21, 77–91 (1996)

RIVER BEHAVIOUR AND HOLOCENE ALLUVIATION: THE RIVER SEVERN AT WELSHPOOL, MID-WALES, U.K.

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Received 18 March 1994
Accepted 20 February 1995

ABSTRACT

A combination of archaeological evidence, ^{14}C dates, terrace mapping, heavy metal analysis, grain size analysis and historical maps is used in a detailed analysis of the alluvial history of the River Severn floodplain around Welshpool in mid-Wales, U.K.

'Welshpool Gravels' underlie a higher terrace surface up to 6–7 m above the present channel. They form a sequence of gravels at least 30 m in thickness. The upper surface is characterized by a series of braided palaeochannel patterns. These sediments were probably deposited at the end of the last glaciation as outwash, and are contemporaneous with other high, gravelly terrace deposits found in the Severn and other mid-Wales basins.

Overlying the Welshpool Gravels on the contemporary floodplain are a variable thickness of finer sediments, the 'Leighton Silts'. Morphological mapping and dating of two cut-offs to 2850 ± 60 a BP and 1190 ± 70 a BP indicates that a channel pattern similar to the present planform had formed by the mid to late Holocene. From this period, floodplain development has been dominated by a single-thread meandering channel with fine vertical sedimentation and limited lateral gravel accretion. Abandonment of extended lengths of channel formed by an avulsion mechanism is apparent.

A combination of historical map data, ^{14}C dates and the analysis for heavy metals in fine sediments, which were washed into the river system during mining, indicates that there has been at least 4 m of sedimentation since the early 17th century, but only in a central belt of varying width. Metal-rich waste, identified in the fine sediments of this zone of 'Trehelig Silts', indicates those areas which were most heavily sedimented during the peak of metalliferous mining in the 18th and 19th centuries. Although the near-channel margins appear to be superficially similar to the older floodplain, the spatial and vertical pattern of historic sedimentation is complex, and is not reflected in marked elevation differences.

The division of sedimentation periods into these three broad time-spans (Late Quaternary Terraces, Late Holocene alluviation and avulsion, and the historical metal-mining period) shows that an apparently simple planar floodplain is in reality underlain by complex sedimentation units. Floodplain construction has involved the development of inset units, in cut-offs and adjacent to migrating channels, as well as the expected contrasts between in-channel and overbank environments. This has implications both for alluvial sedimentation modelling and for the identification of high-pollution zones on the floodplain. These cannot be predicted on the basis of simple 'in-channel' and 'overbank' environments given the historically complex evolution.

KEY WORDS alluvial; sedimentation; Holocene; heavy metals; floodplain; palaeochannel

INTRODUCTION

As the number of precise stratigraphic surveys of floodplains grows, the range and complexity of recognized floodplain types has been extended. Nanson and Croke (1992), for example, have suggested a wide range of prototypes, classified according to stream power and sediment size. Complexity is also provided by alluvial histories, which are characterized by environmental changes of natural or human origin, because of fluctuations in river regime and sediment supply (Knox, 1983). This means that physical sedimentation models (e.g. Bridge and Leeder, 1979; Howard, 1992) predicting the spatial extent of particular alluvial units or the grain-

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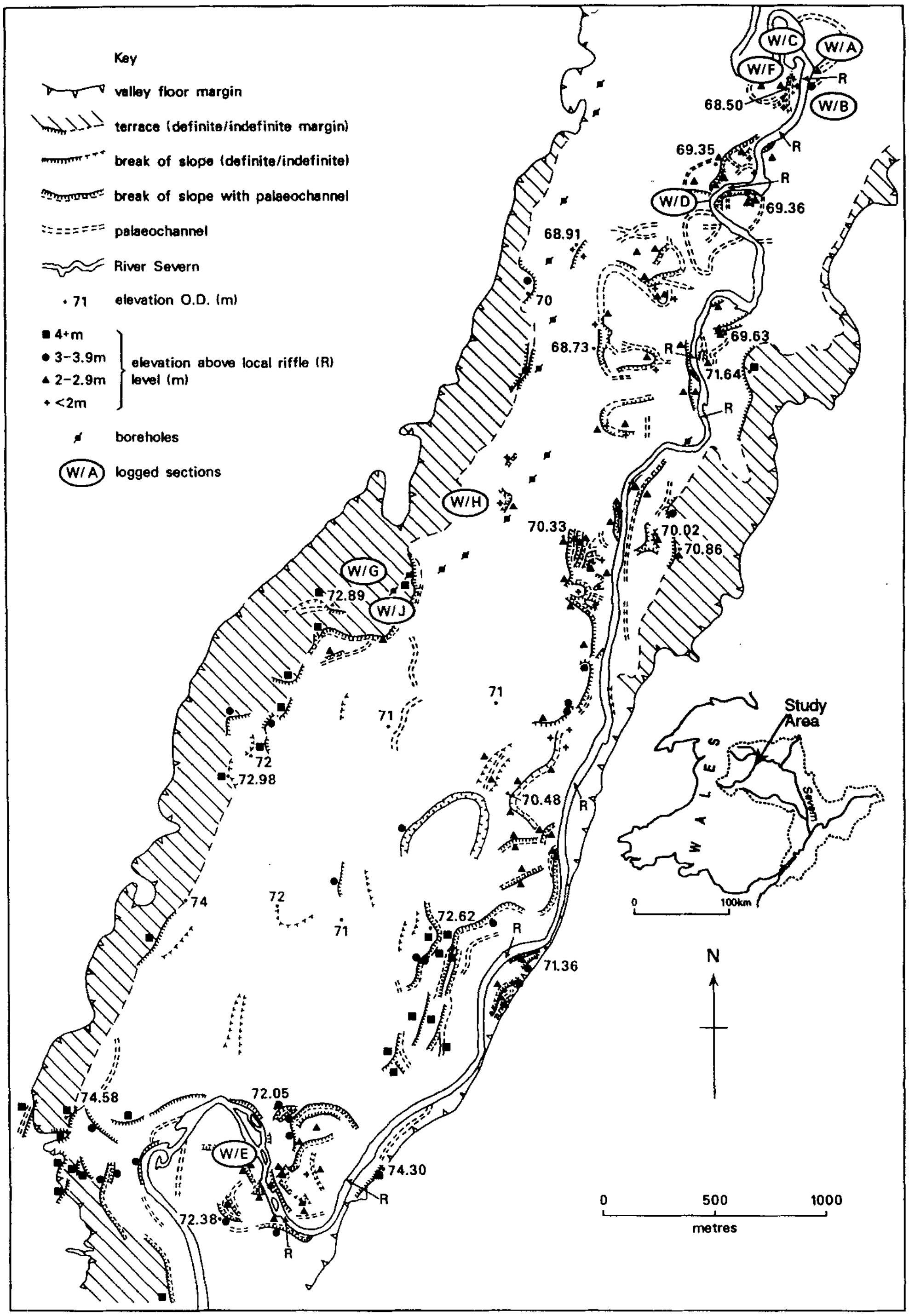

Figure 1. Geomorphological map of the floodplain at Welshpool. Channel flow is SW–NE

size characteristics of sediments across a floodplain, need to be reconciled with the evolutional development of modern floodplains. It is important to establish actual floodplain histories, specifically for determining the location of historically deposited polluted materials. In this site study, we aim to establish the variable rates and spatial patterns of alluviation, in what looks, superficially, like a rather uniform floodplain surface, using multiple field and laboratory methods.

The area of floodplain studied at Welshpool is approximately 6·5 km in length and up to 2 km wide (see Figure 1). It lies in what may be described as the piedmont zone (Newson, 1981) at the base of the Cambrian mountains from where the River Severn rises on Plynlimon (752 m). The catchment area of the River Severn at Welshpool is 876 km^2 and is dominated by Lower Palaeozoic Ordovician and Silurian siltstones and sandstones. The sediments from these rocks are found as gravel-sized bed materials in the contemporary rivers of the Upper Severn Basin. The finer materials that are transported as suspended sediments represent a combination of the mechanically abraded products of these gravels and inwash from valley soils. The numerous glacial events that have affected the Welsh landscape have produced a glaciated valley trough at Welshpool, while leaving behind a variable capping of Quaternary deposits, the majority of which owe their origin to the last glacial event which had its maximum at *c.* 18–20 ka BP (Campbell and Bowen, 1989).

FIELD AND LABORATORY METHODS

Sedimentary exposures in the field area (Figure 1) were logged and sampled. Terrace-top sediments, palaeochannels and sediment exposures in the floodplain created by trenching, and river cut bank sediments, of different ages and environments, were analysed. Once sediment samples had been collected and air dried, the coarse fractions were sieved for 15 min at 0·5ϕ intervals from -6ϕ to 4ϕ. The fine fractions (4ϕ to 9ϕ) were analysed for grain-size distribution on a Micromeritics Sedigraph 5100. The two datasets were combined and their composite size characteristics specified using moment measure statistics (after Lindholm, 1987). Organic content was estimated using the loss-on-ignition technique proposed by Ball (1964). A sub-sample of the $< 4\phi$ fraction was analysed for the element contents by an inductively coupled plasma mass spectrometer (ICP-MS) (see Thompson and Walsh, 1983), and nickel, copper, zinc, cadmium, barium and lead concentrations in the sediments will be considered here. A total of 171 samples were analysed. Heavy-metal content for sediments from field site W/F, a 3·5 m cut bank section (Figure 1) analysed by Watts Stelling at the University of Newcastle-upon-Tyne in 1986, were used as part of the dataset (see Macklin *et al.*, 1994). Sixty-nine samples from vertical sections were analysed for lead, zinc, copper and cadmium by atomic absorption spectrophotometry (air/acetylene flame) using a Phillips SP2900 double beam.

Floodplain survey

In order to provide semi-quantitative data on the morphology of the alluvial surface, the floodplain study area from Dyffryn Farm (SJ 209 015) to the meandering channel zone just south of Leighton Bridge (SJ 237 069) was mapped and surveyed for palaeochannels, terrace remnants and breaks of slope on a 1 : 10 000 O.S. map (Figure 1). Terrace and palaeochannel elevations were determined using an electronic distance measurer. Heights were achieved for floodplain features by their level relative to the nearest accessible O.S. spot height. On occasions when floodplain features were not visible from an O.S. spot height, a temporary bench mark was created and the height transferred. Riffle heights were achieved in the same manner. Map elevations are given in two forms on Figure 1: relative to O.D., and by symbol in relation to local elevation.

Boreholes and exposures in the floodplain

Prior to the construction of a by-pass around Welshpool during the period 1990–1993, Wallace Evans and Partners carried out a substantial trial pit and borehole survey of the proposed route across the floodplain and terraces (see Figures 1 and 2 for selected boreholes and their relative positions). National Power plc. released the drilling data for their borehole no. 169 (213 055), approximately 50 m from the present channel in the study area. This borehole shows the floodplain at this point to be underlain by 1·2 m of silts in the upper section, then 4 m of gravels, below which silts and sands dominate until 18·4 m where gravel is again encountered.

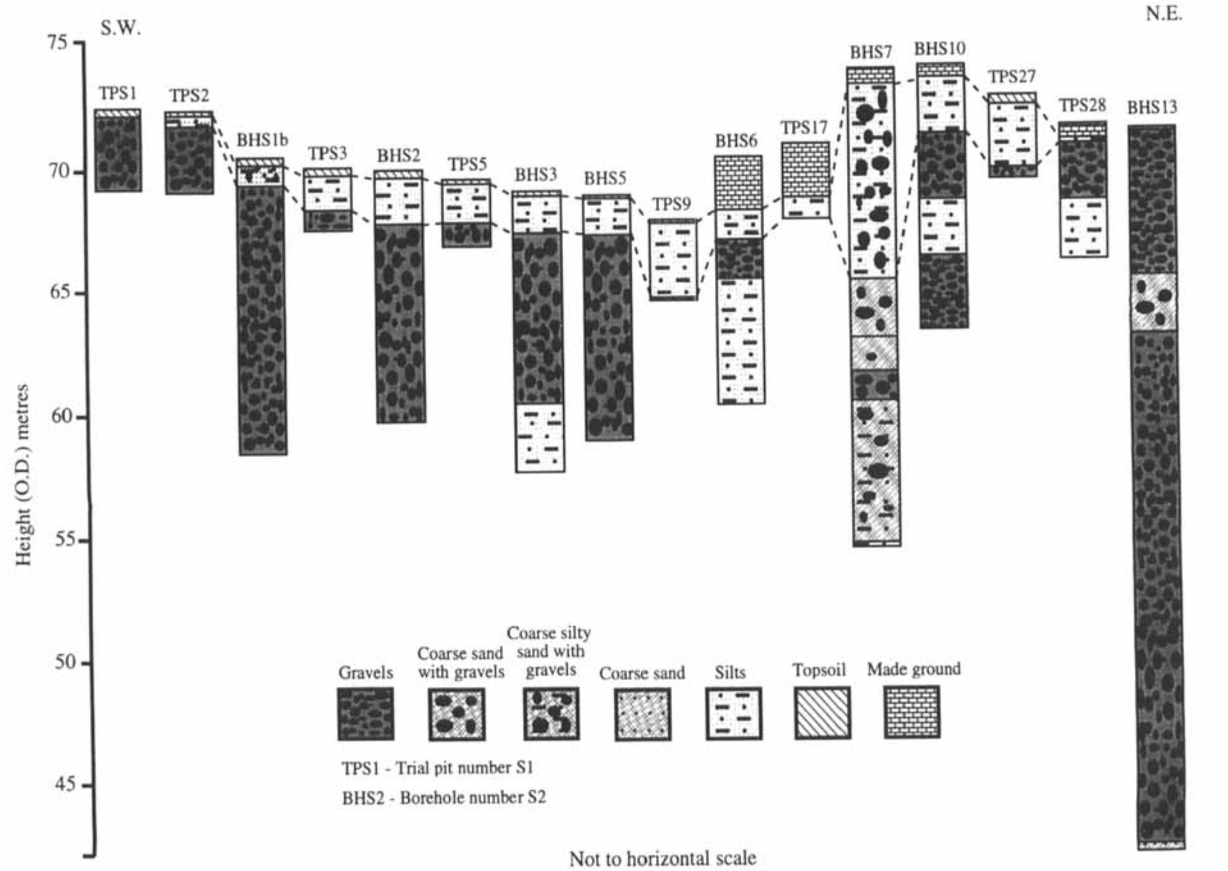

Figure 2. A selection of boreholes that were drilled for the construction of the Welshpool by-pass (source: Wallace Evans and Partners borehole logs). The Leighton and Trehelig Silts are shown by the dashed lines. The sediments underlying these fine units are contiguous with the Late Devensian Welshpool Gravels

Cut bank sections

In addition to the borehole data, five river bank sections, W/A–W/E (see Figure 1), were logged in detail and sampled for grain size, organic and heavy-metal contents. Where organic materials were available, samples for ^{14}C dating were taken. The selection of sites was in part dictated by accessibility and the availability of sediment exposures from vertical and lateral erosion.

Excavations of palaeochannels

Two phases of excavation took place, in November and December 1990, and involved the exposure of terrace sediments at site W/G (SJ 219 049) (Figure 1) and across a palaeochannel at site W/J (SJ 219 047) at the foot of this terrace, some 1 km from the present channel of the River Severn. A third excavation took place in August 1991 and involved the excavation of another palaeochannel at site W/H (SJ 225 045) at a lower floodplain elevation (see Figure 1), 0·5 km from the present river channel.

FLOODPLAIN MORPHOLOGY AND THE ALLUVIAL STRATIGRAPHY AT WELSHPOOL

The River Severn down to its junction with the Afon Vyrnwy (SJ 327 158) displays a variety of channel styles and morphologies. These range from a high width–depth ratio gravel-bed channel 50 km upstream of Welsh-

pool at Llandinam (SO 019 871) which is laterally migrating and rapidly reworking the present valley-floor sediments, to one in silty sediment, with a low width–depth ratio, near the Vyrnwy junction. In such areas, channel reaches are historically stable and sedimentation is dominated by vertical accretion, e.g. in the study area at Glanhafren (SJ 229 045). Field and laboratory data show that there is increasing dominance of the upper fine unit in near-surface floodplain sediments from ~ 1 m or less around Llandinam (SO 019 871), to ~ 2·5 m downstream of Caersws (SO 055 928), and up to ~ 4 m around Welshpool (SJ 238 073).

The Welshpool floodplain can be divided into four main morphological units. The oldest of these units is that of the 'Welshpool Terrace' which is located at the edges of the floodplain and lies at least 4 m above the present river level at field site W/G (Figure 1). Borehole data and floodplain excavation show that this surface is underlain by large-scale, crudely bedded gravels which are at least 30 m thick (Figure 2). These are informally named the 'Welshpool Gravels'. In addition, aerial photography has revealed a sequence of braided channels in crop marks on the surface of the Welshpool Terrace, and it is thought that these were characteristic of this deposition phase. Adjacent to field site W/G (see Figure 1) is a Neolithic timber pit circle which has been dated to 4400 ± 40 a BP (BM-2820) (Gibson, 1992). This gives a minimum age for the terrace surface, but these gravels were probably deposited much earlier, during the Late Devensian, as outwash deposits. No dateable materials were found within the gravels. Other Late Devensian gravelly terrace deposits with similar sedimentation styles have been described on the Lower Severn (e.g. Wills, 1938; Beckinsale and Richardson, 1964; Shotton and Coope, 1983; Dawson and Gardiner, 1987) and also in the mid-Wales catchments of the Afon Rheidol (Macklin and Lewin, 1986), Clarach Valley (Heyworth *et al.*, 1985), and the valleys of the Vyrnwy and the Tanat which drain into the River Severn downstream of Welshpool (Lewin, 1987a, 1992; Taylor, 1993). Revegetation and slope stabilization in the late-glacial to

Table I. Listing of the ^{14}C dates and the historically derived dates obtained from the Welshpool Field sites. Samples calibrated using a program by Stuiver and Becker (1986)

(a) Radiocarbon-dated sediment sections

Field site location	Height of sample in section (m/metres OD)	Material	Sediment type sample recovered from	^{14}C date (a BP)	Calibrated dates (2 sigma)
W/J Beta-41687	0·71/70·25	Wood	Silty clays	Modern	
W/J Beta-41686	1·16/69·8	Wood	Silty clays	1760 ± 70	AD 70 (255, 305, 316) 430
W/J Beta-41485	2·23/68·73	Wood	Gravels	2850 ± 60	BC 1259 (1047, 1044, 1013) 835
W/H Beta-49605	1·8/66·53	Wood	Silty clays	1190 ± 70	AD 670 (781, 789, 805, 821, 829, 839, 862) 990
W/B Beta-54266	3·6/66·1	Wood	Silty sands	360 ± 50	AD 1430 (1490) 1650

(b) Historically dated sediment sections

Field site location	Sediment type	Years before 1993	Dates
W/A	Silty sands	198	AD 1795
W/C	Gravels overlain by silty sands	149/109	AD 1844/1884
W/D	Silty sands	177	AD 1816

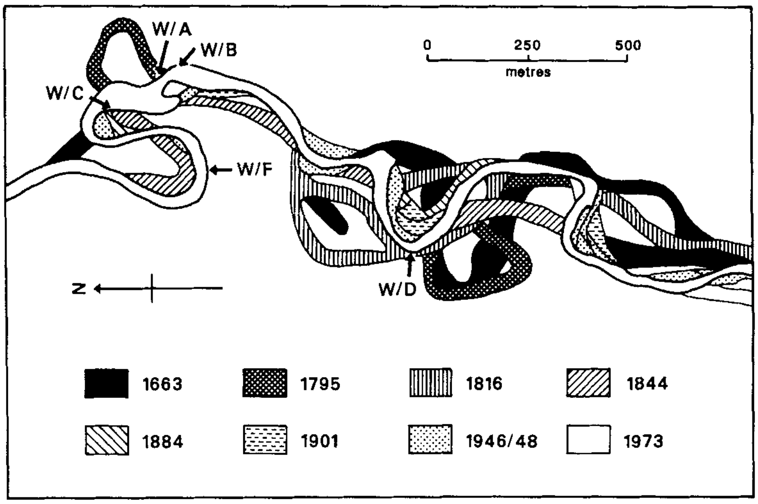

Figure 3. Historical channel map for the lower end of the Welshpool reach (based on Lewin, 1987b). Also indicated are the field sites that occur in this area

early Holocene period were probably responsible for reducing the volume and calibre of coarse sediments entering the fluvial system (cf. Church and Ryder, 1972), leading to a change in sedimentation style from braided to single-thread channels.

A second morphological feature, the 'Older Floodplain', lies at the base of the Welshpool Terrace at the outer edges of the current floodplain. This has a rather featureless surface, but with some long, sinuous palaeochannels and smaller terrace remnants. Lateral sediment exposures of up to 50 m through the floodplain, observed during construction of the by-pass, combined with borehole data (see Figure 2) and the excavation of palaeochannels W/J and W/H (SJ 225 054) (Figure 1) show that the floodplain is predominantly developed on around 2 m of fine sand and silt deposits overlying gravels. The deposition of this fine alluvial unit, (informally named the 'Leighton Silts') is inset below the older Welshpool terrace. ^{14}C dating of the palaeochannel W/J at the outer edge of the Older Floodplain (Figure 1) to 2850 $\pm$ 60 a BP (see Table I for all ^{14}C results) provides a maximum age for this unit. The combination of mid to late Holocene dates from the palaeochannels W/J and W/H (Table I) and morphological mapping of the adjacent surfaces (Figure 1) indicates that a significant change in sedimentation style after the Late Devensian, from gravelly multi-thread channels to a fine-sediment, single-thread system, had occurred by the mid-Holocene.

The development of the Leighton Silts is coincident with the deposition of other Bronze Age fine floodplain sediments, for example in the Warwickshire Avon Valley, 2600 a BP (Shotton, 1978), in the Lower Severn Valley, 2000–3000 a BP (Brown, 1983, 1987), in the Upper Thames Valley, *c.* 2400 a BP (Robinson and Lambrick, 1984), and on the River Tyne, *c.* 2580 a BP (Passmore *et al.*, 1992). These other floodplain sequences are associated with anthropogenic activity and changes in land use in the respective catchments, as well as climatic discontinuities, and are similar in age to other alluvial sequences identified across Britain (Macklin and Lewin, 1993), Europe (Becker and Schirmer, 1977) and North America (Knox, 1983). The Leighton Silts are predominantly derived from eroded soil materials, developed in the earlier Holocene and transported and redeposited later. To this extent, the thick, fine alluvium of the floodplain is in part a response to human occupancy of the landscape.

A third element, the 'Younger Floodplain', occurs nearer the present channel and is distinguishable from the Older Floodplain by numerous small terraces, breaks in slope and palaeochannels, which indicate phases of repeated channel change by lateral migration and channel abandonment, together with resedimentation (see Figure 1). Historical map evidence dating from 1663 allows identification of a zone of historic sedimentation adjacent to the present channel in the lower end of the study area (Figure 3). Evidence for significant historical channel change is only available to the north of the study area, whereas the channel to the south

(for unknown reasons) has remained relatively stable since around 1830, even though there are a number of palaeochannels, dating perhaps from only a little earlier than this, in evidence here (see Figure 1). Cut bank exposures (W/A–W/F, Figure 1) indicate that these sediments (informally named the 'Trehelig Silts'), are sedimentologically very similar to the Leighton Silts. Their formation is, however, coincident with three important environmental changes. These are the 'Little Ice Age' *c.* 1590–1850 AD (Lamb, 1977), an extension of the arable farming and the widespread enclosure of fields by the late 19th century (cf. Chapman, 1991), and the extensive period of 19th century metal mining that occurred in the upper reaches of the Severn Basin (Jones, 1922; Jones and Moreton, 1977; Bick, 1990). Heavy-metal analysis was carried out on the sediments with a view to refining the chronostratigraphy. Previous research into sediments downstream of metal activity (e.g. Wolfenden and Lewin, 1977, 1978; Lewin *et al.*, 1983; Klimek and Zawilinska, 1985; Macklin, 1985; Lewin and Macklin, 1987; Leenaers *et al.*, 1988; Macklin *et al.*, 1992c; 1994) has shown that mining and post-mining alluvial units may be distinguished from the older sediments on the basis of heavy-metal content. To investigate this possibility, the cut bank sections (W/A–W/E, Figure 1) were analysed not only for sediment texture but also for element content.

The fourth feature is the contemporary channel. This is floored by medium to coarse gravels, with finer silts and sands which are transported as suspension-load materials deposited on bar tops and across the developing floodplain as overbank fines during flooding. Where the river has been undergoing lateral migration, e.g. at Gravel Lodge (SJ 237 057), gravelly point bars become abandoned and are then progressively covered with a thin veneer of fine sediments which vertically, laterally or obliquely accrete over time (cf. Allen, 1965, 1970; Bluck, 1971; Nanson and Croke, 1992). The gravelly units may be re-eroded and exposed in cut bank sections due to lateral channel erosion, and they are often overlain by a thicker sequence of very recent fine alluvium, e.g. Trehelig-gro (SJ 213 023), Gravel Lodge (SJ 234 057), and field sites W/B (SJ 238 072), W/C (SJ 237 072) (Figure 1). These finer silts and sands may be deposited incrementally over a matter of years and decades as thin veneers within a channel-migration zone on top of gravels and inset within the general floodplain surface level, or as channel fills in abandoned reaches. In summary, therefore, the floodplain is composed of gravelly bedform features, whose limits are determined by switches in channel location, which are overlain by variable thicknesses of finer silty sands which accrete during flood inundation. Such fines can be thickly deposited in certain locations, especially where ponded or floodwaters permit rapid sedimentation, but they are not spread thickly or evenly across the floodplain surface as a whole under present conditions.

HEAVY-METAL POLLUTION

The Welshpool terrace, the floodplain and older palaeochannel sediments

The most recent floodplain sediments were sampled extensively and a pilot study carried out to establish whether or not those that were associated with small terraces, palaeochannels, or the floodplain surface as a whole were contaminated with heavy metals. Table II shows that the values of heavy metals recorded for the general floodplain surface are largely uncontaminated relative to the local, thick, fine-sediment sequences of recent cut bank exposures at W/A–W/F. Lead values appear to be slightly elevated compared to the other metals in Table II. These data show that although the floodplain has been inundated during overbank flooding events, thick alluvial sedimentation has been spatially restricted. In addition, the older Welshpool Terrace (> 4 m above river level) has remained above historic flood limits. The values obtained for the older palaeochannels W/J and W/H, which have been radiocarbon dated (see Table I), are largely similar to those obtained from the Welshpool Terrace. These may also have been infilled with pre-mining sediment with background levels of element concentrations, and thus are largely unpolluted, even though they are still within present flood inundation limits.

Historical palaeochannel sediments

Two recent palaeochannels, W/A (SJ 238 073) and W/C (SJ 237 072), which can be linked to the period of the historic fine sedimentation (Figure 3), were also analysed. These recent palaeochannels are currently exposed in cut bank sections of the River Severn (Figure 1) and as they have been abandoned within the

Table II. The mean values for heavy metals at each field site. The individual profiles for each of the field sites W/A–W/F are shown in Figure 4

Field site (depositional environment)	Heavy metals (ppm) Ni	Cu	Zn	Cd	Ba	Pb
Older deposits and floodplain sediments						
W/G (outwash deposits)	61·50	46·03	237·25	n.d.	333·53	26·12
W/J (palaeochannel)	53·91	65·78	226·72	n.d.	533·76	29·05
W/H (palaeochannel)	77·61	46·76	188·25	0·79	356·17	23·10
Floodplain $n = 37$	67·98	51·25	222·9	0·55	278·80	60·67
Std deviation	16·15	23·61	87·30	0·44	65·20	38·92
Channel margin sediments						
W/A (palaeochannel)	84·81	56·46	478·03	2·16	247·54	135·72
W/B (overbank)	55·64	30·69	155·84	0·40	188·09	25·62
W/C (palaeochannel)	115·91	67·14	936·35	6·42	297·32	204·07
W/D (overbank)	109·52	56·78	173·42	0·35	274·37	28·39
W/E (lateral accretion/overbank)	109·18	61·63	442·92	1·57	294·25	124·73
W/F (overbank)	18·06	n.d.	152·67	0·92	n.d.	13·21

n.d. = no data

last 300 years they provided a direct modern analogue with which to compare older palaeochannel infills. The data presented in Table II clearly show that there are marked and significant differences between the older and historic palaeochannels, with the historical sediments of W/A and W/C demonstrating enhanced heavy-metal pollution, specifically of lead, zinc and cadmium.

Figure 3 shows that palaeochannel W/C lies in an area that is associated with the 1844 and 1888 positions of the River Severn, with the latter being sedimented during what was the peak period of metal mining activity (Jones, 1922). Th element analyses from W/C show that nickel, zinc, cadmium and lead have greatly enhanced levels in comparison to the Welshpool Terrace, floodplain and older palaeochannel sediments. Interestingly, some of the highest heavy-metal values in sediment section W/C were found towards the base of the section (1·8–2·2 m, Figure 4), coinciding with the coarsest grain sizes. Although a similar pattern is found at field site W/A, where increases in lead values towards the top of the sediment exposure (see Figure 4) were paralleled with increases in grain sizes, the opposite relationship was shown to exist at site W/B. The cut bank sections of W/D and W/E showed no obvious relationships between grain size and metal content. A Pearson's product moment correlation test between grain size and heavy-metal contents confirms that there are no significant relationships, thereby establishing that particle size was not an important factor in controlling element concentrations. The thickness of these fine contaminated units is of considerable significance, since it shows that pollutant contamination is localized according to the history of floodplain sedimentation.

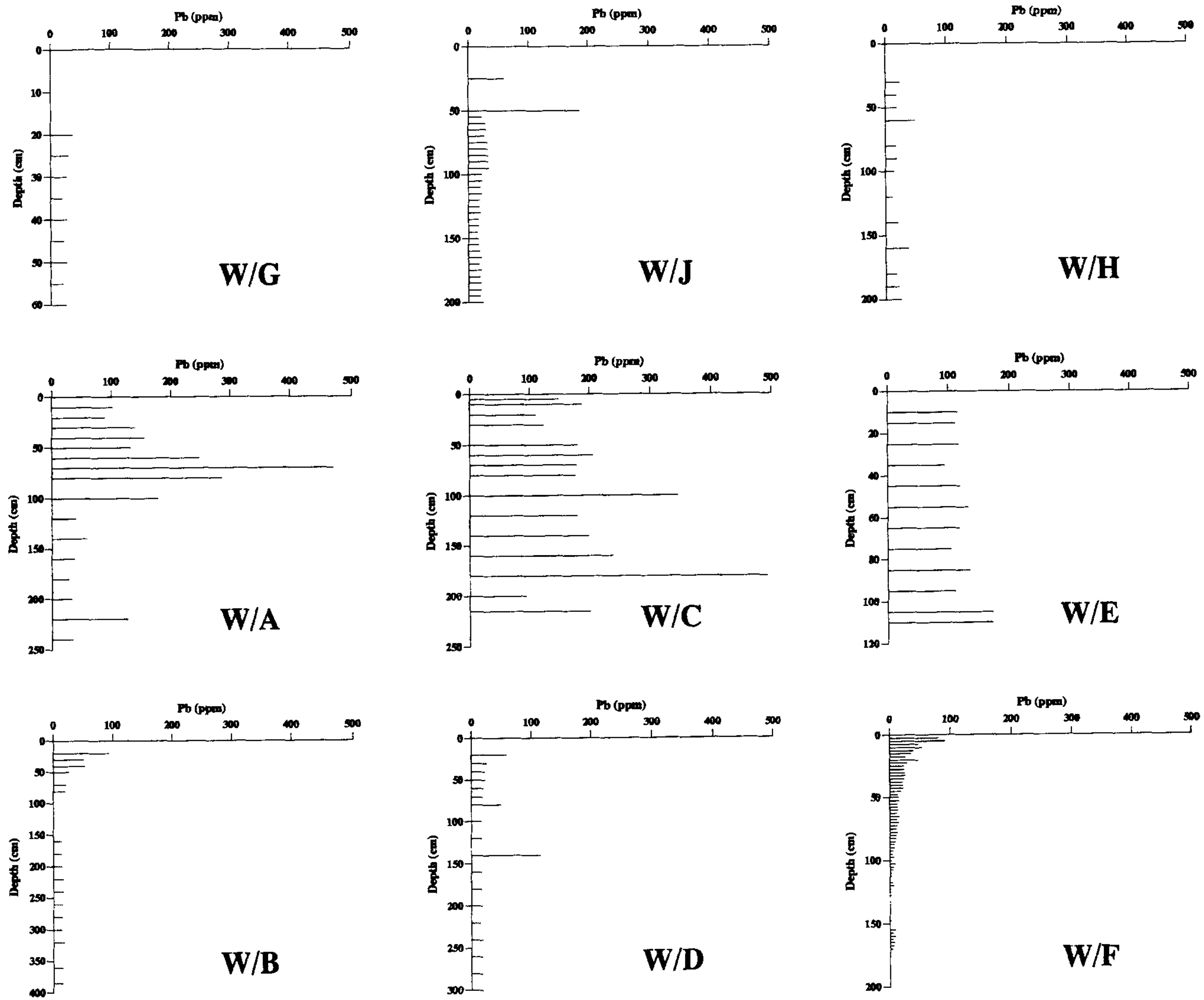

Figure 4. Profiles of the lead values from exposed sediment sections at Welshpool. Sites W/G, W/J and W/H are from older deposits whereas the profiles from sections W/A–W/F are taken from the channel-margin zone. See Figure 1 for field site locations

Sedimentation in the AD 1795 cut-off at palaeochannel W/A was probably initiated slightly earlier than that at W/C (see Figure 3) and, using an averaged sedimentation rate of 1·36 cm a^{-1} (thickness of infill/maximum known date of the palaeochannel), it can be calculated that site W/A would have been infilled by *c.* 67 cm by AD 1844. The sedimentation rates are calculated as a ratio of thickness to time, permitting an average deposition rate at a particular site. They do not account for any variance that may result due to increasing elevation at a site over the dated time period. Due to sedimentation at W/A, this palaeochannel would have been over-topped only by the higher flows, while the younger cut-off of W/C would have been lower and susceptible to inundation much more regularly around the time of peak mining activity, and would thus have received a greater influx of heavy metals.

Channel margin sediments

Four other cut bank sediment exposures (W/B, W/D, W/E and W/F), which consisted of historic fine sediments, were investigated for their heavy-metal content. The sediments at a depth of 360 cm at field exposure at W/B have been radiocarbon dated to 360 ± 50 a BP (Table I). The element analyses from these sediments show that the sediments in the upper section of this profile exhibit relative metal increases over those lower down in the profile, which probably predate the main period of metalliferous mining activity. The up-section increases in lead values at W/B (Figure 4) show that they are somewhat lower than those of the adjacent cut bank exposure at W/A. This is probably a function of the different environments of deposition and relative heights above the river at the time. The depositional environment at W/B is not readily apparent from field or historic map analysis, but it is likely to have been a channel zone in the period prior to the deposition of the Trehelig Silts. By 1795, the date of the cut-off at site W/A, sedimentation and infill at W/B would have meant that this part of the floodplain was over-topped only during extreme flooding. In contrast, the topographic low at W/A would have received floodwaters and polluted sediments more readily than W/B, explaining the elevated levels of heavy metals at this site (Table II).

The results of the element analyses show that the sediments from sites W/D and W/F are largely uncontaminated, and have values for Ni, Cu, Zn, Cd, Ba and Pb similar to those of the older palaeochannels, the floodplain and Welshpool Terrace sediments, even though they are adjacent to the more contaminated sites discussed above (Figure 4). The sediment exposure of field site W/D lies within an area that has been sedimented since 1816 by a combination of in-channel and then overbank sedimentation processes as the channel migrated eastwards across the valley floor (see Figure 3). The historic maps show that the floodplain in the precise area of cut bank exposure W/F has not been affected by historic channel migration, so that material would appear to have accreted as a result of overbank sedimentation processes. The fact that the uppermost sediments at W/F show a similar pattern to those of W/B and W/D, in that the highest heavy-metal values occur towards the top of the section, supports the view that it is just these sediments that have accreted in the mining and post-mining period, unlike those of W/A, W/C and W/E (see Figure 4).

Field site W/E (SJ 213 023) lies towards the up-valley limit of the field study area (Figure 1), and mapping indicates that it too lies in an area of floodplain that has undergone recent lateral channel movement (see Figure 1). Table II shows that average values of metal pollution are higher than those of the prehistoric sediments, with enhanced values of Zn, Cd and Pb, which suggests that it was probably sedimented during the mining or post-mining period. These values are slightly lower than the peak values from palaeochannels W/C and W/A (Table II, Figure 4), which indicates that they may have been mixed and diluted by later unpolluted sediments (cf. Miller and Wells, 1986) in the late 19th century, hence the lower values.

FLOODPLAIN SEDIMENTATION RATES

In addition to the toxic effects of mining waste, an additional impact on the environment has been that of increased sedimentation rates (Table III). Brown (1987) has shown that the most significant impacts on floodplain development of the Lower Severn occurred during Bronze Age deforestation and agricultural expansion, a relationship which has been suggested also in other floodplain studies (e.g. Macklin and Lewin, 1993; Macklin *et al.*, 1992a,b, Passmore *et al.*, 1992; Hooke *et al.*, 1990), and as shown in the Leighton Silts unit.

Table III. Rates of Holocene floodplain sedimentation from different field sites on the River Severn at Welshpool

Field site	Depositional timescale	Sedimentation rate (cm a^{-1})
W/J	2850–1760 a BP*	0·1
W/J	1760–0 a BP*	0·07
W/H	1190–0 a BP*	0·15
W/B	360–0 a BP*	1·0
W/A	1795 AD–0 a BP†	1·36
W/D	1816 AD–0 a BP†	1·69
W/C	*c.* 1844 AD–0 a BP†	2·75

* ^{14}C (uncalibrated) dates
† Dates derived from historical maps

The sedimentation rates presented in Table III and Figure 5 show that locally the most significant rates have occurred over the last millennium rather than during the Bronze Age, with increases of several times those of earlier periods. The most recent increases, over the last 300 years, coincide with the climatic deterioration of the Little Ice Age and the associated hydro-climatic impacts (Harris, 1985; Lamb, 1977), the effects of converting scrubland to grazing pasture following the 1845 Enclosure Act (cf. Chapman, 1991) which involved widespread vegetation, and of the proliferation of 19th century metal-mining activity in the headwaters of the River Severn. The combination of increased storm events and intensities and land use change in the upper catchment may well have increased overland and peak flood flows. These could quite feasibly have combined to erode exposed topsoils and also to excavate areas of channel bank which had been destabilized as a result of phytotoxic damage to vegetation (cf. Lewin *et al.*, 1983) as a result of the increased heavy-metal pollution from the upstream metal-mining activity (Jones, 1922; Jones and Moreton, 1977; Bick, 1990). Acceleration of the rates of lateral channel shift, providing channel-side opportunity for thick sedimentation of fines below flood level, may also have been affected by some of these factors.

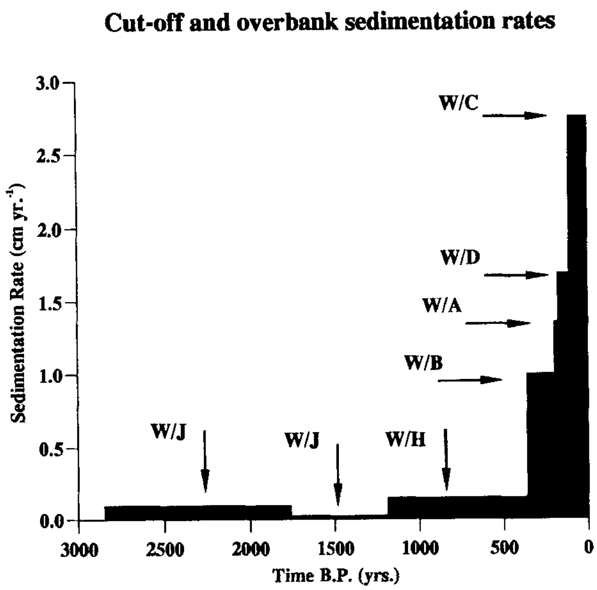

Figure 5. Changes in floodplain sedimentation rates during the Late Holocene on the River Severn, at Welshpool. Refer to Figure 1 for field site locations

Although the magnitudes of the various environmental impacts are difficult to distinguish and quantify retrospectively, the effect of agriculture, mining and/or settlement on relatively undisturbed areas has been well documented in numerous river valleys (e.g. Shotton, 1978; Butzer, 1980; Harvey *et al.*, 1981, 1984; Lewin *et al.*, 1983; Robinson and Lambrick, 1984; Pope and van Andel, 1984; Macklin and Lewin, 1986; Klimek, 1988). The data presented here appear to show that the Upper Severn floodplain at Welshpool has also responded to various Holocene environmental perturbations, but in a variable temporal and spatial manner. The fine-sediment fills of the so-called 'historic' period (medieval onwards) accumulated within a limited zone of rapid migration and sedimentation near the active channel, probably at a much greater rate than in older palaeochannels at an earlier period, and more rapidly than for the floodplain as a whole.

DISCUSSION

The sediments of the floodplain at Welshpool have been shown to be composed of three main alluvial units: the Welshpool Gravels, the Leighton Silts, and the Trehelig Silts. These units are summarized in Figure 6. A similar set of sedimentary units has been identified in a neighbouring catchment of the Upper Severn Basin in the region of the junction of the Afon Tanat and the Afon Vyrnwy (SJ 244 207) (Lewin, 1987a, 1992; Taylor, 1993), which may suggest that the units identified at Welshpool have both a local and regional significance. Holocene alluviation here has been of a type intermediate between the lateral accretion model of high-energy river environments with active channel migration, and the vertical sedimentation model of lower-energy environments where channels are non-migratory. However, it is more complex than this because alluvial behaviour has changed over time (in response to environmental change), and a younger alluvial unit is set within and is contiguous with an older one to which it is superficially very similar (with silts overlying gravels associated with meandering channel styles). The depositional history of the sedimentary units appears to have been more strongly influenced by human activities in the catchment as opposed to climatic forcing mechanisms (e.g. Macklin *et al.*, 1992a; Rumsby and Macklin, 1994), with older forms (such as palaeochannels) functioning under different conditions alongside more recent alluvial features. The Welshpool floodplain, characterized by numerous lengths of abandoned channel and complex spatial and historical sedimentation patterns, represents a previously unidentified intermediate behavioural type. The misleading simple channel and floodplain form need to be recognized so that evolutionary processes and mechanisms can be determined more accurately.

The presence of heavy-metal pollutants in the Trehelig Silts has permitted a deeper understanding of the variable response of the floodplain to sedimentation processes during the last few hundred years. Although

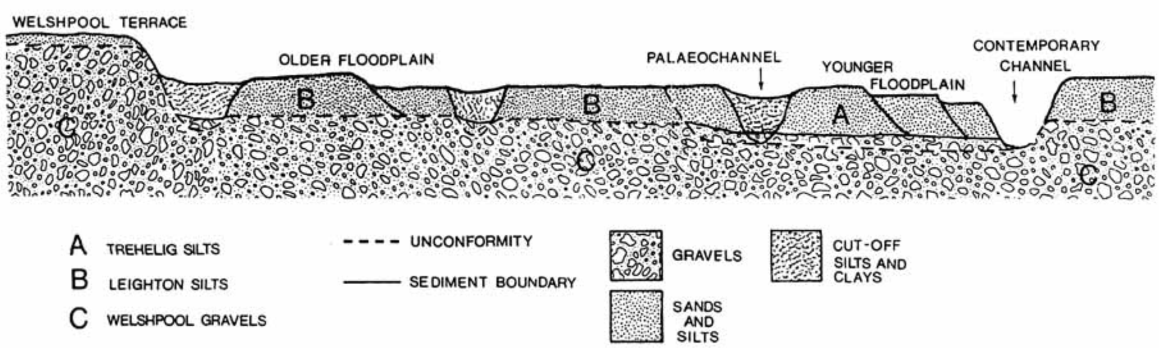

Figure 6. Schematic cross-sectional diagram showing the major alluvial sedimentary units of the Welshpool floodplain

the grain sizes and sediment characteristics are largely similar amongst all the floodplain sites, the quantity of metals found in the near-channel and floodplain-surface sediments (of similar age) is extremely varied. Although the average values for the sediments at site W/B are relatively low, there are significant increases in the relative concentrations of metals in the upper 1·5 m of the profile. The maximum values recorded for Pb, Zn or Cd are much lower than those from the palaeochannels W/A and W/C (Figure 4). Comparison of the results from the top 1·5 m of field site W/B with those of field site W/D indicates that the sediments have similar levels of Ni, Cu, Zn, Cd, Ba and Pb (see Table II). The sediments from site W/D were deposited under similar conditions to those of W/B, at first as in-channel and then as overbank environments, and they have heavy-metal values comparable to the floodplain. This contrasts with the environments of deposition for field sites W/A and W/C (and probably W/E), which were former channel-margin environments during the peak of metalliferous mining.

Although contaminated sediments were readily available in the fluvial system during the 19th century, they were not deposited uniformly across the floodplain. Hughes and Lewin (1982), Marriott (1992) and Magilligan (1992) found that the mean grain size tended to decrease with distance from the channel, and Allen (1965) noted that 'floodplain deposits form a single though variable textural group'. Lambert and Walling (1987) suggested that microscale variations in deposition rates were probably due to topography, with depressions on the floodplain receiving the highest amounts of deposition. Morphological mapping of the floodplain shows that it is composed of a variable topography, with the element analysis results indicating that the most contaminated zones are those within the historic channel migration zone. This probably occurs due to the development of quiet backwater environments, in open channels but away from high floodwater velocity zones, where sediment metal content is enhanced by the deposition of finer particles which are normally held in suspension in the turbulent waters of higher flow-velocity environments. Although Gretener and Stromquist (1987) and Lambert and Walling (1987) have discussed general accretion rates of floodplain sediments, the data presented here clearly show that historically differentiated areas of the floodplain are subject to variable sedimentation rates depending on the environment of deposition, the topography and relationships to the river channel at the time of deposition. It is no simple matter to identify when and at what rate different portions of morphologically contiguous and apparently highly similar floodplains were actually sedimented. This is of considerable importance if the location and distribution of contaminated zones on the floodplain are to be reliably identified, or indeed if the volume of polluted materials is to be estimated.

CONCLUSIONS

The floodplain at Welshpool is divisible into three major alluvial units: the Welshpool Gravels deposited in Late Devensian; the Leighton Silts deposited since the Bronze Age; and the so-called Trehelig Silts which have been deposited in the last 300 years.

Across the floodplain there are important spatial and temporal variations in the distribution of polluted sediments. The Welshpool Gravels and the Leighton Silts remain relatively unpolluted compared to the Trehelig Silts; these have been deposited in the last 300 years, but are rather similar in form, elevation and texture to the Leighton Silts. It does appear that the highest concentrations of heavy metals can be found, in places, in quite thick units, in bar-top fines of near-contemporary active migrating channels, and in cut-offs, rather than simply in flood-prone areas related in some way to distance from the channel in overbank environments. Variations in channel-margin topography and sedimentation style are important factors in controlling the deposition and sedimentation of contaminated materials.

The most significant Holocene floodplain developments appear to have occurred in the last 200–300 years and are probably attributable in unknown proportions to the combined impacts of metalliferous mining, agricultural development and the improvement of land for grazing, and the hydro-climatic impacts of the Little Ice Age. Probably at the late-glacial–early Holocene transition channel planform metamorphosis occurred, transforming the braided and outwash deposits of the Late Devensian. This period, and that which followed human occupation in the mid-Holocene, appears to have been an extended phase of slower floodplain development, typical of a more meandering river pattern.

ACKNOWLEDGEMENTS

This work was carried out when M.P.T. was in receipt of a NERC studentship at the Institute of Earth Studies, University of Wales, Aberystwyth. We would like to thank Clwyd–Powys Archaeological Trust for their assistance in gaining access to field sites, Dr Paul Brewer for help with field work, Mike Gelly Jones for drawing Figures 1 and 3, and Harold Edwards and Dr Bill Perkins for assistance in the preparation and analysis of samples on the ICP-MS. We thank Dr Mark Macklin for permission to use the metal analyses carried out at Newcastle University by Watts Stelling.

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